# Slippage in Models : The Impact of Boundary Conditions


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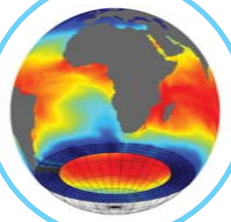
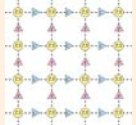


## Techie stuff

### The NEMO Model

In the implementation at NOC, the NEMO model is run with 75 layers in the vertical, ranging in thickness from 1m at the surface to ~200m at depth. Portrayal of bottom flow is improved by the use of partial cells i.e. the cell at the bottom of the water column may include the sea bottom at some intermediate height.

The grid co-ordinates correspond to an Arakawa C-grid i.e. mean water properties (T,S) on the cross-points of a lattice, with the velocity components (U,V) located midway along the respective axes. The model is constructed on the ORCA tri-polar grid, with the i,j co-ordinates conforming to a Mercator longitude-latitude grid in the southern hemisphere (of interest here), but warped slightly in the northern hemisphere to place poles in both Canada and Russia (thus avoiding singularities associated with small grid cells within the ocean domain. The three resolutions used correspond to equatorial grid cells of size 1°, 1/4° ("eddy-permitting") or 1/12° ("eddy-resolving").

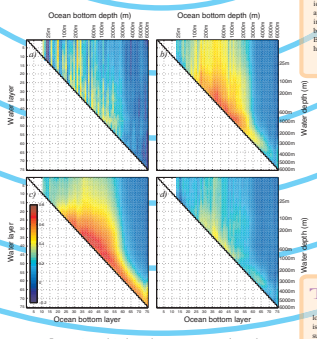


The model was initialised according to the World Ocean Atlas 2005, and all the runs shown here experienced realistic forcing, with 6-hourly winds and daily heat and freshwater fluxes from the DFS4.1 dataset.

### Boundary Conditions

At a land-ocean interface the flow normal to the boundary must be zero. However there are different ideas as to what constraints if any are required for the flow parallel to it. For C-grid models, the normally applied condition is termed "free-slip", where there is no friction along the surface and thus there is no shear in the flow at the boundary. An alternative formulation, called "no slip" requires the current along the boundary to tend to zero as the interface is approached. This was the conventional choice for models on a B-grid e.g. OCCAM. (Intermediate conditions "partial slip" can be implemented, but are not considered here.)

$$\nabla v_{\parallel} \cdot \hat{n} = 0 \quad \text{or} \quad \nabla v_{\parallel} \cdot \hat{n} = 0$$




*Topotropy: i.e. correlation between long-term mean current and expected direction for topographic Rossby waves. a) 1° b) 1/4° c) 1/12° free-slip runs, and d) 1/4° no-slip run*

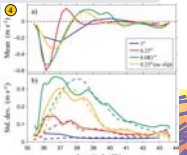
### Topostrophy

Topostrophy is the term introduced by Merryfield & Scott (2007) to describe the tendency of the long-term mean current to align with the direction of propagation of topographic Rossby waves i.e. along isobaths. Close to the sea-bed the steering will be strong, but mean currents will be less constrained nearer the surface. Effects will also be stronger where the bathymetric gradient is strongest. Following the approach of Penduff et al. (2007) we calculate the dot product of unit vectors along mean flow and along depth contours, weighting each according to cell volume and intensity of gradient:

Applied to our 4 runs (evaluated in a global context) we note that increased resolution heightens the steering of the mean flow, but that a change to "no slip" conditions markedly reduces the alignment.


### Abstract

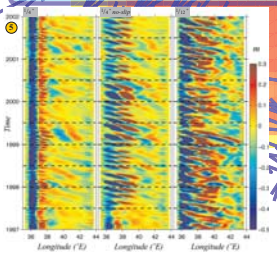
Drakkar is a pan-European consortium investigating model sensitivity by running multiple versions of the NEMO z-layer model with various settings for the model parameters. This poster examines 4 of these runs, contrasting changes associated with spatial resolution, with the effects produced by an alternative choice of lateral boundary conditions. Whilst finer resolution (and consequently longer run times) generally improves the realism of a model, other choices appear to have a similarly positive impact without the processing cost.

*a) Mean meridional flow at 21°S in different model runs; b) Variability (std. dev.) of meridional currents (full line) and zonal current (dashed line)*

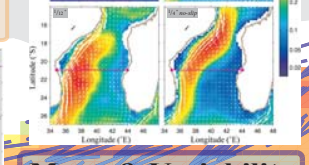
### Hovmoller Analysis

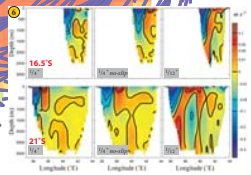
The figure below shows near-surface meridional velocity at 21°S as three of the models. The 1/4° free-slip run shows a permanent poleward flow at the coast, and an offshore equatorward return, with both showing weak pulsing at approximately annual frequency. The no-slip version has a much more pronounced variability at 5-7 cycles per year, which is found in observations, and the 1/12° run shows a periodicity of 4-5 events per year, with the features emanating from much further eastward than in the 1/4° no-slip case.



### Mean & Variability

Given the very different dynamical responses in the models (Fig.2) it is intriguing to look at the mean surface flow in each (vectors in Fig. 3). Aside from the 1° model, all show a significant WBC in the mean, with a weaker return flow 150 km or further offshore. Fig. 4a shows the mean poleward flow in the 1/4° no-slip run to have a shower peak than the corresponding free-slip run, but *the broader mean flow* produced by its eddies agrees with that of the 1/12° run. In terms of variability the no-slip run is much more energetic than the 1/4° free-slip run, and the pattern of variability matches recent high-resolution altimetry products even better than does the 1/12° run. Note the variability is approximately isotropic (Fig. 4b), with the two runs with eddies producing much more variability in offshore currents, which are needed to transport riverine sediment and nutrients from the east channel.






### Full-depth analysis

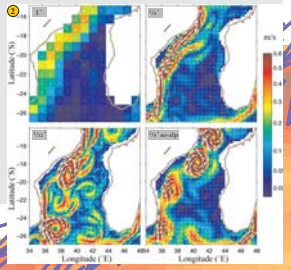
Vertical sections of the mean flow at 16.5°S (the narrowest part of the Channel) and 21°S show the mean flow along the western boundary to extend to at least 1000m depth, with evidence of Mozambique Undercurrent flowing equatorward below that. "No-slip" conditions forces the current further offshore, where bottom topography is also more sloping bathymetry, it is more prone to instabilities and the generation of eddies. The mean undercurrent is much stronger in the 1/4° no-slip run than in the free-slip, and the surface return flow further offshore. Zonal jets seen in the climatological full-depth fields, as well as the 5-day fields of the models at each location. The eddies in the 1/4° no-slip run is 7 Sv less than for all resolutions using free-slip. This difference is seen in the model results collated by van der Werf et al (2010) once the significance of boundary conditions is realised. However the amplitude of the seasonal cycle, which depends upon the seasonal wind-forcing to the east of Madagascar (Matano et al., 2008) is unaffected by the choice of slippage.

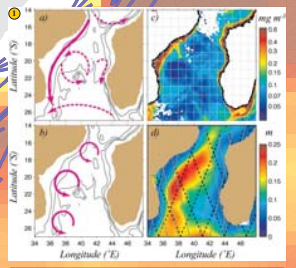
| *NEMO Model* | *Mean (Sv)* | *Seasonal change (Sv)* |
|---|---|---|
| *1°* | *24.9* | *5.1* |
| *1/4°* | *26.3* | *5.0* |
| *1/12°* | *24.9* | *7.1* |
| *1/4° ns* | *17.3* | *5.4* |

*Mozambique Channel transports in the different NEMO runs. (All seasonal cycles peak in Sept-Oct.)*

### Instantaneous View

Snapshots from each of the 4 model runs show very different portrayals of the flow (colour shows speed): a) 1° model shows a broad western boundary current (WBC); 1/4° free-slip run has a more intense WBC plus offshore return; c) 1/12° shows a maelstrom of eddies and detached current; d) 1/4° no-slip run produces a regular set of mesoscale eddies, similar to those shown in ocean colour (above).

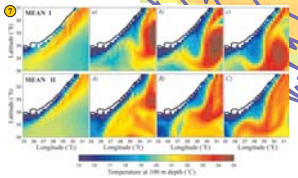




### Reality & Models

Our conceptual picture of the flow in the Madagascar Channel has changed radically over the last two decades from a focussed western boundary current with possible mid-basin gyres (e.g. Saetre & Jorge da Silva, 1984) to one of a steady train of anticyclonic eddies. This concept has emerged from altimetry and cruise data (de Ruijter et al., 2002), with ocean colour imagery sometimes providing a clearer synoptic picture (Quartly & Srokosz, 2004). Altimetry shows the variability to lie in the western half of the channel.

Most numerical models used in a variety of applications from operational tracking of pollutants or drifting ships to understanding our present climate and its sensitivity to change, it is fundamental to ask whether the models we use show the correct dynamical features. For example, models will clearly lead to different drifter trajectories from a steady along-shore flow. Instabilities further downstream in the Agulhas Current are associated with anticyclonic eddies (either from Mozambique Channel or from south of Madagascar). If these are suppressed in the channel then variability downstream may be affected. Finally, many species have been cited at animals (turtles, great frigate birds, cetacean species) in this region, and would have their behaviour is related to physical structures associated with aggregation of prey. Any biogeochemical model for studying ecosystem dynamics in the region will need to contain appropriately sized eddies to transport coastal biomass and nutrients away from the coast.

### Puzzle Corner

And the idea? Now see if you can work out which model means are shown in I and II (below), and which runs the time series a)-b)-c) and A)-B)-C) showing Natal Pulses come from (snapshots in series are 10 days apart).